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ABSTRACT

Rapidly increasing population growth and food requirements call for increases in agricultural production, especially in irrigated areas. Environmental impacts arising from farming intensification in groundwater irrigated areas worldwide are manifold and the Life Cycle Assessment (LCA) is very relevant for assessing these impacts. But a regional LCA can not be done by transferring the "standard" product-oriented methodology to this meso-scale, especially in a context of data scarcity. Our objective is to propose a methodology to build a regional-scale Life Cycle Inventory (LCI) that would account for farming system diversity, avoid double counting and make clear allocation rules within this multi product system. We propose to base this methodology on the Agrarian System Diagnosis (ASD). This approach leads to a typology of farming systems which reflects the different agricultural exploitation modes existing on a regional scale. Enquiries are then carried out in farms representative of each type in order to build the inventory, which leads to a reduction of the uncertainty. This approach was applied on a case study located in Tunisia. Nine existing farming system archetypes and their main agricultural practices were identified and linked to their natural and socio-economic conditions. This typology goes beyond the farming system structure to describe its functioning and dynamics. Being a valuable approach for building a regional LCI, the agrarian system diagnosis could also be useful when assessing the environmental impacts of agricultural products at farm and crop scale. Indeed, this method allows us to build a typology of realistic situations instead of a virtual average system, and to support better allocation for multi product systems.

Keywords: variability, LCI, irrigation, agrarian system diagnosis

1. Introduction

Rapidly increasing population growth and food requirements call for an increase in agricultural production, out of 40% is provided by irrigated areas. The International Water Management Institute has called for "more crop per drop" (Molden, 2007). And drip irrigation is endorsed as it is less water intensive par area than surface irrigation. But eventually this technique led to manifold indirect environmental impacts such as cropland extension, global input intensification and groundwater overexploitation due to individually managed tube wells . It is therefore essential to develop tools in order to assess the impact of various agricultural planning scenarios in irrigated areas.

Life Cycle Assessment could be a candidate tool. As public water management and decision making is carried out, Life Cycle Assessment (LCA) should be applied at regional scale, which is still a methodological challenge (Guinée et al., 2011). In spite of being product oriented, several authors underline LCA relevancy at regional scale, namely for a farming region, defined as a set of farms in a given geographical area (Aubin, et al., 2011; Payraudeau and Van der Werf, 2005).

Accounting for the variability of farming systems and management practices is one of the main challenges in agricultural LCA (Nemecek et al., 2010). Unlike the case described by Payraudeau et al., (2005), the farm population in an irrigated area is too large to be surveyed one by one. Reviewing 70 LCA studies conducted in tropical and semi-arid locations, Basset-Mens et al. (2010), highlighted the failure to account for farming system diversity and the lack of specific data and data collection methods. Building up farm typologies is a way of dealing with the great variability of flows related to agricultural practices (Dalgaard et al., 2006). Some studies already performed LCA at regional scale. At this scale, statistics e.g. the Farm Accounts Data Network (FADN) were used for building farm typologies (Dalgaard et al., 2006, Mishima et al., 2005), mainly because they are in line with LCA for being product oriented (Weidema and Meeusen 2000). Nonetheless, this approach cannot be widely applied: on the one hand, very few countries in the world offer agricultural statistics device and on the other hand these statistics are based on economic inputs and outputs (I/O) and thus present several drawbacks for LCA purposes. Agriculture is poorly described by I/O because it is mainly dependent on many self produced resources (Haas, et al. 2000) and also because data are expressed in monetary units; a large uncertainty (Huijbregts, 1998) is then linked with major environmental impacting flows such as fertilizers and chemicals. Moreover, the European Commission, (2010) mentioned that when performing a LCA, data related to the foreground system, i.e. field scale agricultural production, should be inventory specific.

Facing a double challenge of data scarcity in the context of Southern countries and high variability of crop management practices in irrigated areas, we propose a new methodological framework to model activity data and build a regional model of agriculture, with the objective of reducing the uncertainty. In this paper, we propose to adapt the methodology of agrarian system diagnosis for modelling farming systems to create as accurate as possible Life Cycle Inventories. This methodological framework enables us to characterise the uncertainty linked to the "real world variability" and to imprecision also called epistemic uncertainty (Huijbregts, 1998). Preliminary results of the agrarian system diagnosis conducted in Tunisia are presented. Finally relative pros and cons of this methodological framework for conducting a regional LCA are discussed.

2. Material and Methods

2.1 Adapting the methodology of Agrarian System Diagnosis for building a Life Cycle Inventory at regional scale

Below is a brief description of the several steps of the Agrarian System Diagnosis (ASD) hereafter designated "diagnosis" and of adaptations made for LCA purposes (right column). This framework for building LC inventory should allow us to reduce the global uncertainty in the LCA; this demonstration is part of the results.

Step n°	Major Steps of Agrarian Systems Diagnosis	Original Agrarian Systems Diagnosis	Agrarian Systems Diagnosis **<u>LCA oriented</u>**
0	Choice of a pilot zone Study of available information sources: Maps, previous studies (soil, slope, climate, water resources…)	Selection criteria: Most of knowledge	Selection criteria: Worst case with regard to potential environmental impacts
1a	Landscape analysis / identification of agro ecological units (soil, slope…) and pre-types of cropping and livestock systems	Identify cultivation dynamics, spatial distribution	Identify vulnerable areas with regard to major impacts
1b	Historical analysis / interviews Climate hazards frequency	For capturing past differentiation processes.	Identify innovative systems Foresee potential evolutions
2	Surveys of cropping and livestock systems (diversity, varieties, soil fertility management, animal feeding calendar…)	Focus on spatial distribution, crop sequences, crop-animal interactions	Investigate co-product destination, material flows between farms
3a	Sampling design of farms to be surveyed for each farming system pre-type (steps 1 &2). Sampling criteria: maximise diversity, farms chosen according to criteria explaining diversity.	Farms illustrating differentiation processes	Focus on potential environmental impacts drivers (contrasted yields, fertilizers and agrochemicals). Select farms with most records.
3b	In depth interviews of Farming Systems: techno-economic characterization: cross-checking of qualitative and quantitative information, iterative process, systems triangulation procedure	Focus on Practices and Economy Focus on farm strategy, opportunities and bottlenecks linked to capital, labour force…	Focus on input/output quantification (e.g. fertilisers & Agrochemicals), including internal flows
4	Extrapolation to the whole area	Based on local knowledge about the representation of each type in the whole area.	Only necessary for "snapshot" LCA, not for agricultural planning scenarios.

Table 1. Proposed methodology for adapting the Agrarian System Diagnosis (ASD) to Life Cycle Assessment.

We propose to mobilize the Agrarian System Diagnosis (ASD), hereafter designated "diagnosis", to model the agricultural region for LCA purposes. ASD was initially designed for targeting farm diversity in development projects. For being systems oriented, ASD aims at understanding the diversity and complexity of regional agricultural production modes at different scales and then model them into a farming systems typology. Farming systems all together are interconnected and compose the agrarian system at the regional scale (Cochet, 2011). Each farming system is modelled as functionally representative of a set of comparable production units. These units carry out a given combination of cropping systems (crop rotation and associated cultivation practices) and livestock systems and rely on comparable resources and socio-economics constraints (Cochet and Devienne, 2006; Moreau et al., 2012).

The modelling process is progressive but not linear, and iterative with several feedback procedures. Table 1 is a brief description of the several steps of the ASD and of some adaptations made for LCA purposes. Starting from a global standpoint by analysing landscape heterogeneity on maps (# 0) and in the field (#1a), several hypothesis about spatial distribution of cropping systems are formulated. Then, assumptions are checked during field surveys (#2) and cropping systems are modelled; other hypothesis on their combination are made into a pre-typology of farming systems. For each pre type, a set of representative farms is sampled (#3a) and in depth interviewed (#3b). Finally, an archetype is designed, whose agricultural practices and economical values are modelled for a “normal year”, i.e. exceptional events are not modelled (#1b). The archetype is modelled for being for the most probable case according to the farm structure, its objective, opportunities and constraints. This approach is system-oriented: it uses triangulation for ensuring data reliability, cross checking structural, functional and historical information about farming systems. In the same vein, disciplinary viewpoints and scales of analysis enrich data consistency. Finally, technical and economic thresholds are calculated for each farming system for outliers identification. A restitution to surveyed people and local expert allows us checking data completeness and validating their reliability.

2.2 Characteristics of the irrigated plain of Kairouan, Tunisia

Located in central Tunisia, in semi arid to arid climate, area under study is an alluvial plain of 30 000 ha and comprises around 2 000 farms. Agriculture has much evolved with drip irrigation introduction, from sheep herding and rain fed cereals and low density olive groves to irrigated vegetables, fruit orchards and high density olive groves. Groundwater provides irrigation water and is overexploited. Nonetheless, economic profitability of irrigated crops led people to drill unauthorised boreholes. A pilot area of 6 000 ha out of 30 000 ha was selected for being a hotspot in terms of water exploitation and intensification of agricultural management practices, i.e. several crop cycles per year and numerous intercropping. Data were collected by two students during a three month stay.

3. Results

Hereafter, we demonstrate how the new framework based on ASD for LCI can support the characterization of uncertainty sources in a regional LCA and public decision making for land planning options. Uncertainty sources are manifold when aiming at modelling the Life Cycle Inventory of an agricultural region. They are usually separated into variability of the “real world” and uncertainty (Huijbregts, 1998).

3.1 Methodological output: the Agrarian System Diagnosis as a methodology to characterise uncertainty in agricultural Life Cycle Inventories

Figure 1 describes the sources of uncertainty in LCI of agricultural systems and the solutions proposed to characterise them via the ASD framework

In the upper part of the figure, uncertainty sources found at the regional scale are listed, in line with uncertainty classification proposed by Huijbregts (1998). In the lower part the way the Agrarian System Diagnosis contributes to characterise each uncertainty source is explained. In the very bottom part we describe how regional LCA outcomes can support public land planning decision making.The *Variability between Sources and Objects* (VBSO) stands for the “differences in inputs and emissions of comparable processes in a product system”; *parameter uncertainty* is caused by inaccurate, unrepresentative, incomplete data e.g. chemicals specifications; *uncertainty due to choices* originates from choices made regarding allocation, Functional Unit, and the LCIA stage that is out of our scope; model uncertainty also occurs during the LCIA stage.

Five out of the six categories of uncertainty sources are addressed by the ASD. Only model uncertainty is totally beyond our study scope.

As explained above, uncertainty related to variability of farming systems and management practices is addressed by building a functional typology of farming systems and cropping / livestock systems based on practices modelling. Practices are contextualised and different from standard technical guidelines.

The typology allows accounting for VBSO❶ and spatial variability over the studied region. Then, a sample set of farms is in-depth interviewed for each identified type. Intra type variability (VBSO❷) should be less than inter-type variability (VBSO❶). If not, a new type should be designed by splitting the type with high variability. Exceptional values due to temporal variability (e.g. climate hazards) for instance and looking inconsistent with regard to the functioning identified are discarded. The archetype built at farm scale is drawn after parameter uncertainty has been reduced and allocations have been made clear; This is done respectively by running several procedures of data consistency checking (cf. part 2.2) and by surveying the whole farming system and interconnections between farms.

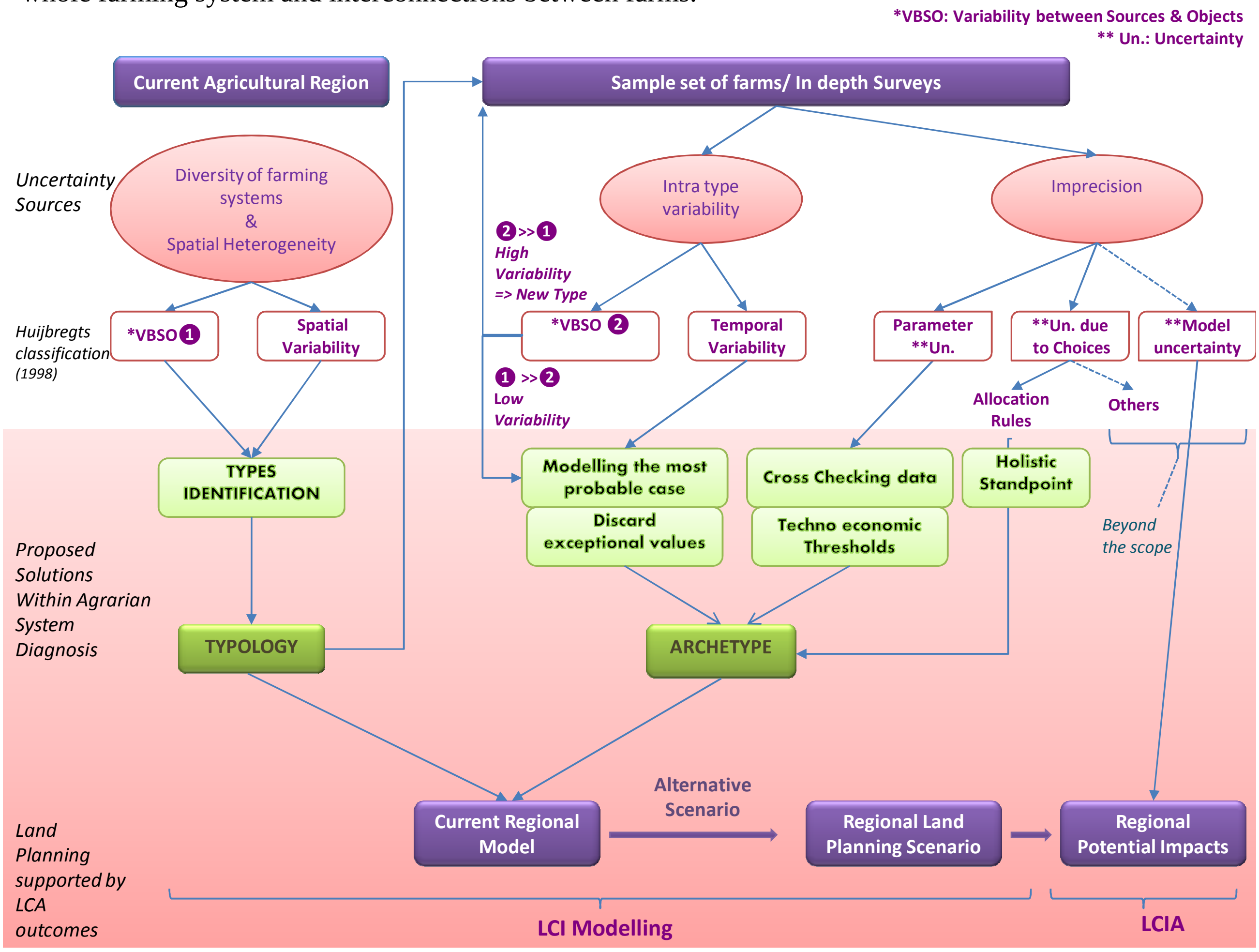

Figure 1. Sources of uncertainty in LCI of agricultural systems and solutions proposed to characterise them within the Agrarian System Diagnosis (ASD) framework

3.2 Preliminary Results

Nine archetypes of farming systems and sub systems (cropping and livestock systems) were modelled in the pilot area, illustrating a high variability. A large range of cultivated species, crop sequences and associated crop management practices were identified. This is usual in irrigated areas because rainfall is no more a limiting factor for growing crops. Olive groves, a crop shared by most of farming systems, is part of very diverse cropping systems. Indeed, density, irrigation management and intercropping vary among olive-grove based cropping systems. Vegetables intercropping is widespread, mostly during unproductive stage of perennial crops. The smaller the cultivated area is, the more crops are intercropped. The level of intensification regarding crop inputs and water quantities vary from a factor one to five. Land productivity is high in case of several crop cycles per year or overlapping crop cycles. These results illustrate the degree of complexity of cropping systems in irrigated areas, especially in case of intercropping, and the need for having a typology-based inventory.

Indeed, the methodology proposed for archetype modelling enable us to design the typology, according to uncertainty source and also according to its magnitude in case of "Variability Between Sources and Objects".

4. Discussion

The objectives of a farming system typology for LCA purposes were: “to lower data variability, thereby allowing a better selection of representative farms for detailed research; better determine the marginal effects of a studied change.” (Lindeijer and Weidema, 2000).

The methodological framework we propose, namely the ASD-based LCA is a powerful method for LCA-oriented data collection that accounts for farming systems and practices variability and provide LCA specific activity data “for a marginal supplementary effort.” ASD is of higher interest since farming systems and sub systems modelling are based on in depth analysis of agricultural practices that are to be turned into LCI data. Consistency of each type is ensured by calculations of technical and economical thresholds. The consistency of activity data is also enhanced by collecting data at different scales, crossing field observations and farm and literature surveys.

The farm archetype that is modelled is neither a virtual farm average (Basset-Mens et al., 2009; Dalgaard et al., 2006) nor a single farm chosen by experts for being representative (Haas et al. 2005). On the contrary, regarding temporal variability, the farm archetype is built for a “normal year” whereas statistics or farm accounting data would refer to a single year. Thus, yields were “modelled” to represent a normal year, instead of being averaged. For example, due to climate hazards yields of pepper ranged from 1.6 to 3.2t/ha; the “modelled” yield was 3t/ha and the average one 2.5t/ha, i.e. there is a 25% difference which would change significantly the LCA outcomes, especially if impacts are expressed per mass unit.

Parameter uncertainty can be large if used data are not specific. In ASD-based LCA we are able to calibrate our own data collection to LCA requirements and include critical flows expected to heavily impact conversely to statistics and FADN data (Dalgaard et al., 2006). Indeed, fertilisers elements, agrochemicals properties and details about intercropping are crucially lacking into these generic databases. Extension services acknowledge that some values, such as cultivated areas in intercropping systems, can be registered twice in local statistics (personal comm.); this may be highly misleading since this practice is widespread on our field study.

ASD allows us to identify innovative cropping systems and current tendencies even if in minority, conversely to statistics already outdated when published. The holistic standpoint provides important insights regarding allocation rules. Indeed, statistics prevent the LCA practitioner from designing allocation rules among the numerous products of the farm, especially mixed ones which are highly represented in our study area. Efole Ewoukem et al. (2012) highlighted that mixed up farming systems tend to make the most of their limited resources and allocate biomass among several productions, thus making allocation rules more complex. Other limitations of the statistic approach for building farming systems typology is that farm functioning cannot be described (Dalgaard, 2000), by-products and near-to-zero values are overlooked (Lindeijer and Weidema, 2000), and data could be too much aggregated (Cochet and Devienne, 2006).

5. Conclusion

ASD demonstrated its ability to help us designing and characterising typical farming systems and their crop and livestock components, in qualitative and quantitative terms. This method of typology is particularly relevant when data are scarce and key criteria for classifying the population of farms cannot be taken from statistics nor from expert knowledge (Dalgaard et al., 2006; Haas et al., 2005). The agrarian system approach decreases uncertainty linked to the inherent variability of “real agriculture” (i.e. farming systems and management practices). Unlike statistics that process data and deduce mathematical correlations between variables, this approach make causalities clear within the frame of each farming system functioning.

Moreover, by revealing material and energy interconnection flows between farms or within a farm, it allows for clearer burden allocation rules among the different product systems. Double counting could also be avoided through the ASD holistic standpoint. Indeed, farming systems that are diversified are likely to support interconnection flows and thus would particularly benefit from this approach.

In addition, this work supports the identification of each farming system’s room for manoeuvre to mitigate their environmental impact, within agro-ecological and technical values that define their range of existence.

Based on this methodology and the typology, our next objective is to complete the characterisation of farming systems archetypes, conduct LCA and lastly assess alternative land planning scenarios for agriculture based on the diagnosis outputs.

6. References

Aubin, B., Donnars, C., Supkova, M., Le Perchec, S. et Dorin, B., 2011. Méthodes D'évaluation. Panorama Critique. in duALIne - Durabilité De L'alimentation Face à De Nouveaux Enjeux. Questions à La Recherche, (Coords.), , in: N. Esnouf, C., Russel, M. et Bricas (ed.) Pour Une Alimentation Durable. Réflexion Stratégique duALIne. Paris, pp. 164–184.

Basset-Mens, C., Benoist, A., Bessou, C., Tran, T., Perret, S., Vayssières, J. and Wassenaar, T., 2010.Is LCA-based Eco-labelling Reasonable ? The Issue of Tropical Food Products, in *Lcafood2010.uniba.it*.

Basset-Mens, C., Kelliher, F. M., Ledgard, S. and Cox, N., 2009. Uncertainty of Global Warming Potential for Milk Production on a New Zealand Farm and Implications for Decision Making. The International Journal of Life Cycle Assessment 14, (7) 630–638.

Cochet, H., 2011. L'agriculture Comparée, Quae, Paris.

Cochet, H. and Devienne, S., 2006. Fonctionnement Et Performances Économiques Des Systèmes De Production Agricole : Une Démarche à l 'échelle Régionale. Cahiers Agricultures 15, 578–583.

Dalgaard, R., Halberg, N., Kristensen, I. S. and Larsen, I., 2006. Modelling Representative and Coherent Danish Farm Types Based on Farm Accountancy Data for Use in Environmental Assessments. Agriculture, Ecosystems & Environment 117, (4) 223–237.

Dalgaard, T., 2000. Farm Types – How Can They Be Used to Structure, Model, and Generalise Farm Data? , in: B. P. Weidema and M. J. . Meeusen (eds) Agricultural Data for Life Cycle Assessment.Vol. 2. The Hague, pp. 98–114.

Efole Ewoukem, T., Aubin, J., Mikolasek, O., Corson, M. S., Tomedi Eyango, M., Tchoumboue, J., Van der Werf, H. M. G. and Ombredane, D., 2012. Environmental Impacts of Farms Integrating Aquaculture and Agriculture in Cameroon. Journal of Cleaner Production 28, 208–214.

European Commission, 2010. ILCD Handbook - General Guide for Life Cycle Assessment-detailed Guidance, Ispra, Italy.

Guinée, J. B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Ekvall, T. and Rydberg, T., 2011. Life Cycle Assessment: Past, Present, and Future. Environmental science & technology 45, (1) 90–6.

Haas, G., Geier, U., Frieben, B. and Köpke, U., 2005. Estimation of Environmental Impact of Conversion to Organic Agriculture in Hamburg Using the Life-Cycle-Assessment Method, .

Haas, G., Wetterich, F. and Geier, U., 2000. Life Cycle Assessment Framework in Agriculture on the Farm Level. International Journal of Life Cycle Assessment 5, (6) 345–348.

Huijbregts, M. A. J., 1998. Application of Uncertainty and Variability in LCA. Part I: A General Framework for the Analysis of Uncertainty and Variability in Life Cycle Assessment. International Journal of Life Cycle Assessment 3, (5) 273–280.

Lindeijer, E. and Weidema, B. P., 2000. Conclusions of the Working Group on Farm Typologies , in: B. P. Weidema and M. J. . Meeusen (eds) Agricultural Data for Life Cycle Assessment.Vol. 2. The Hague, pp. 145–146.

Meeusen, M. J. . and Weidema, B. P., 2000.Agricultural Data for Life Cycle Assessments, in *European Invitational Expert Seminar on Life Cycle Assessment of Food Products*.

Mishima, S., Taniguchi, S. and Komada, M., 2005. Adaptation of Life Cycle Assessment (LCA) to Agricultural Production on a Regional Scale in Japan. Ecology 81, 671–678.

Molden, D., 2007. Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture., London.

Moreau, P., Ruiz, L., Mabon, F., Raimbault, T., Durand, P., Delaby, L., Devienne, S. and Vertès, F., 2012. Reconciling Technical, Economic and Environmental Efficiency of Farming Systems in Vulnerable Areas. Agriculture, Ecosystems and Environment 147, (1) 89–99.

Nemecek, T., Knuchel, R. F., Alig, M. and Gaillard, G., 2010.The Advantages of Generic LCA Tools for Agriculture : Examples SALCAcrop and SALCAfarm, in *Life Cycle Assessment in the Agri-food Sector*.

Payraudeau, S., Van Der Werf, H. M. G. and Vertès, F., 2005. Evaluation of an Operational Method for the Estimation of Emissions of Nitrogen Compounds for a Group of Farms. International Journal of Agricultural Resources, Governance and Ecology 5, 224–246.

Payraudeau, S. and Van der Werf, H. M., 2005. Environmental Impact Assessment for a Farming Region: a Review of Methods. Agriculture, Ecosystems & Environment 107, (1) 1–19.